FogRoute: DTN-Based Data Dissemination Model in Fog Computing

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***Abstract*—Fog computing, known as "cloud closed to ground," deploys light-weight compute facility, called Fog servers, at the proximity of mobile users. By precatching contents in the Fog servers, an important application of Fog computing is to provide high-quality low-cost data distributions to proximity mobile users, e.g., video/live streaming and ads dissemination, using the single-hop low-latency wireless links. A Fog computing system is of a three tier Mobile–Fog–Cloud structure; mobile user gets service from Fog servers using local wireless connections, and Fog servers update their contents from Cloud using the cellular or wired networks. This, however, may incur high content update cost when the bandwidth between the Fog and Cloud servers is expensive, e.g., using the cellular network, and is therefore inefficient for nonurgent, high volume contents. How to economically utilize the Fog–Cloud bandwidth with guaranteed download performance of users thus represents a fundamental issue in Fog computing. In this paper, we address the issue by proposing a hybrid data dissemination framework which applies software-defined network and delay-tolerable network (DTN) approaches in Fog computing. Specifically, we decompose the Fog computing network with two planes, where the cloud is a control plane to process content update queries and organize data flows, and the geometrically distributed Fog servers form a data plane to disseminate data among Fog servers with a DTN technique. Using extensive simulations, we show that the proposed framework is efficient in terms of data-dissemination success ratio and content convergence time among Fog servers.**

***Index Terms*—Data dissemination, delay-tolerant network (DTN), Fog computing.**

I. Introduction

FOG COMPUTING [1], [2] is an emerging technology to provide high quality engaged localized services. The Fog computing extends Cloud services by deploying Fog servers at the physical proximity of mobile users, e.g., parks and shopping malls. This provides a local software defined "customized Cloud" accordingly at user's premises with dedicated cloud which possesses processing, storage, and network transmission ability. Compared with centralized Cloud services, such as Amazon EC2 and IBM SoftLayer, Fog computing spreads its facility at distributed locations surrounding users, and accordingly provides more engaged, localized mobile services tailored to the deployment sites, e.g., streaming applications, localized advertisements, and sensor networks. In order to provide the seamless services in wide areas, Fog servers are geographical distributed and managed by a central cloud controller. They can be widely deployed in remote rural area, city center, moving vehicles, and autonomous systems to support a very large number of nodes, which means wireless enabled devices could use Fog computing technique in anytime, anywhere, and anyhow.

Fog computing typically has a three-tier Mobile–Fog–Cloud structure [3]. In the Mobile tier, it could include all wireless devices, such as smartphones, tablets, and laptops. In the Fog tier, Fog servers provide services to the end users and synchronize data with the Cloud. In the Cloud tier, Cloud provider provides content service required by geo-distributed Fog servers. Data dissemination between a mobile user and a Fog server is occurred when this mobile user retrieves content. If this Fog server has the required content, it sends the content to the mobile user. Otherwise, this Fog server needs to send a query to its Cloud provider to find and download it into its local storage. On another side, Fog servers need to regularly check with their Cloud providers whether the Fog servers have the updated contents or not; if not, they need to update their storage by retrieving from the Cloud via either wired or wireless networks, e.g., cellar networks. Such data disseminations may involve a huge cost due to the large data volume. According to the report from Cisco [4], the overall mobile data traffic is expected to grow to 24.3 exabytes per month by 2019 and more traffic will be offloaded from cellular networks, such as Fog devices, than remains on cellular networks by 2016.

参考文献

The motivation of this paper is the "two-latency" problem in Fog computing. The first "latency" is the time to deliver the demanded content to mobile users. Streaming applications are becoming more and more popular, while the long latency may severely affect the user experience and is not tolerable. To address this issue, Fog computing moves Cloud services from remote Internet to the edge of networks and makes streaming content much closer to mobile users, which significantly decreases the streaming latency. On the contrary, the data dissemination from Cloud to every Fog servers can be expensive, particular for the areas without a fast and reliable Internet access. In addition, note that since the majority of streaming applications are video-based, such as movies, teleplay, and product advertisement, such contents are not always necessary to be strictly up-to-date and one or two days latency is

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affordable, which is the second latency. Consequently, data dissemination for the high volume and nonurgent data among Fog servers becomes promising and delay-tolerant network (DTN) technique makes it available. In summary, the contributions of this paper are threefold.

1) *Practical System:* We have developed a practical Fog computing-based content dissemination framework in vehicular networks. The proposal makes use the delay tolerant model and also the Cloud computing framework.
2) *Distributed Algorithm:* We have developed a fully distributed algorithm to enable the low-latency and low-cost content disseminations in the vehicular Fog computing system.
3) *Performance Evaluation:* We have conducted extensive simulations to verify the performance of the proposal. It is show that our proposal can achieve a low end-to-end delay of data dissemination with high successful probability.

The rest of this paper is organized as follows. Section II reviews the existing models and introduces the background of Fog computing. Section III describes the hybrid data dissemination model in details. Section IV analyzes simulation performances of the proposed model. Finally, Section V summarizes this paper and provides suggestions for future works.

II. Background and Related Works

A. Fog Computing

Fog computing [3], [5]–[7] is an emerging paradigm to extend the Cloud service to the "ground," where applications or contents located on far away worldwide Cloud servers are now distributed to a multitude of Fog servers located just in local business premiss, on-board or even the outdoor, which can also be used in urban computing [8]. These Fog servers have process, storage, and network transmission capabilities. Mobile users access Fog servers with just one-hop wireless connection, and therefore streaming applications for majority of mobile users become available even at the area in a poor Internet coverage. The transmission speed from Fog server to mobile user is much faster than the speed from remote Cloud to end users. For example, the IEEE 802.11ac WiFi has a speed around 2600 Mb/s in its 5 GHz band, while the most latest 4G LTE Advanced cellular network only have a speed around 1000 Mb/s.

WiFi 速度

As Fog computing is a promising paradigm, several papers have discussed its definition, purpose, characters and research trend, such as. In this section, we mainly focus on the following real applications or architectures under the umbrella of Fog computing.

A Fog computing network is managed by a central Cloud server. This accordingly makes Fog computing a three-tier hierarchy structure, Mobile–Fog–Cloud. There are three bidirectional data dissemination modes in this model: 1) *Mobile to Fog*; 2) *Mobile to Cloud*; and 3) *Fog to Cloud*. *Mobile to Fog* data dissemination is the main purpose of Fog computing paradigm, where majority of contents used in a particular location have been predownloaded from Cloud to this Fog server. Mobile users can easily access these resources, such as using WiFi technique, with a very high transmission speed and a reliable network environment. High quality streaming applications become available with a low cost. In the case if a Fog server has not the content a mobile user requested, *Mobile to Cloud* data dissemination is used. In this mode, end user can directly retrieve content from Cloud provider, which is the same as the current Cloud model. In order to provide this Fog computing service, Fog servers need to get the up-to-date contents from Cloud service provider by using the *Fog to Cloud* mode. This data dissemination mode is usually conducted by Internet connection, such as ADSL, cable network, and optical network. For these Fog servers under mobile environment or pool broadband coverage areas, cellar or even satellite network is used.

B. Data Dissemination Based on Delay-Tolerant Network Technique

For high volume and nonurgent data, it is not wise to use expensive network transmission techniques. Instead, DTN technique could be used to provide data dissemination between Fog servers, and between mobile users and Fog servers as well.

DTN [9], [10] is featured with long latency and unstable network topology, where end-to-end delay can be measured in hours or days and data dissemination paths may not exist. Data dissemination in DTN uses store-carry-forward techniques; if there is no connection available at a particular time, the source node needs to store and carry the message until the next available node is encountered.

DakNet [11] is a DTN technique-based application and developed by researchers from the MIT Media Lab. It has been deployed in remote parts of Cambodia and India at a cost two orders of magnitude less compared to traditional landlines networks. DakNet uses existing communications and transport infrastructure to form a DTN, where it combines physical transportation with a wireless data transferral function to extend Internet connectivity to a central hub, such as cyberspace or a post office. DakNet does not need to relay data over a long distance, which is an advantage because it would reduce costs and save a lot of power. Instead, DakNet transmits data over short point-to-point links between kiosks and portable storage devices called mobile access points (MAPs). An MAP can exchange data among public kiosks, Internet enabled devices, and non-Internet accessed hubs by using mobile generators mounted on and powered by a bus or motorcycle.

The point-to-point data transfers use high bandwidth with low-cost WiFi radio transceivers. When an MAP-equipped vehicle comes within range of a WiFi-equipped kiosk, it automatically detects the wireless connection and uploads/downloads tens of megabytes of data. On the other hand, when the MAP-equipped vehicle comes within range of an Internet access point, it automatically synchronizes the data generated from rural kiosks. This application creates a low-cost DTN and asynchronous data exchange infrastructure. This process would be sufficient to provide the daily information services for a small village with only one small vehicle passing everyday.

As demonstrated above, DTN technique could be used as a low cost data dissemination method in Fog computing, particular for data dissemination among Fog servers and mobile devices. If these become available, data traffic between Fog server and Cloud could reduce dramatically. In order to implement it, two main carriers are used in this DTN-based data dissemination, human associated DTN [12]–[14] and vehicle-based DTN [15]. Most of mobile devices, associated with Fog servers, are either carried by human or mounted on vehicle. The movement pattern of human carried devices are predictable and these devices can be utilized to carry small to medium size content to provide an offload data dissemination in human associated DTN [16]. The movement pattern of vehicles are classified in the following three categories.

1) *Fixed Route:* Vehicles move to the predefined destination with preconfigured routes, such as shuttle bus and train.
2) *Flexible Route With Fixed Destination:* Vehicles move to the predefined destination with different routes, such as taxi and GPS enabled car.
3) *Expected Route:* Vehicles move along a certain road, such as the road between two intersections.

III. HYBRID DATA DISSEMINATION IN FOG COMPUTING

As identified above, the current data dissemination model in Fog computing is not efficient for these high volume and nonurgent content. In this section, we present *FogRoute*, a hybrid data dissemination model using Fog computing, which takes advantages of DTN technique to offload content among Fog servers either by human or vehicle. The first section introduces the new model to support this hybrid data dissemination. The second section presents how the hybrid data dissemination works in Fog computing topology, and the last section discusses privacy and reliability issues of FogRoute.

A. System Model

To have an efficient data dissemination in Fog computing, DTN is used to offload data transmitted among Fog servers. In Fig. 1, if Fog server A has some small contents, such as a new video ads, but Fog server B does not. In previous, Fog server B needs to get the update from Cloud server directly. With DTN technique, user 1 could download this content when he has a coffee in this cafe shop. After a couple of hours, he goes to shopping center for shopping. When he moves into the transmission range of Fog server B, this content storied in user 1's mobile device automatically upload to Fog server B and this store-carry-forward process is finished. For large content, e.g., a high definition movie, transmitted from Fog server B to Fog server A, vehicle-based DTN is used. In this example, if car 2 is parked in the shopping center and within the Fog server B's transmission range, it downloads this movie into its local storage. Once this vehicle moves to the transmission range of Fog server A, this movie is uploaded to it and this data dissemination is completed.

In addition of the above DTN-based data dissemination between mobile user and Fog server, direct data dissemination from Fog server to Fog server based on DTN technique

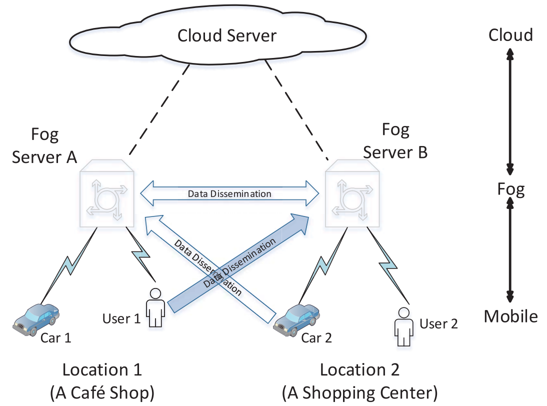

Fig. 1. Data dissemination in Fog computing based on DTN technique.

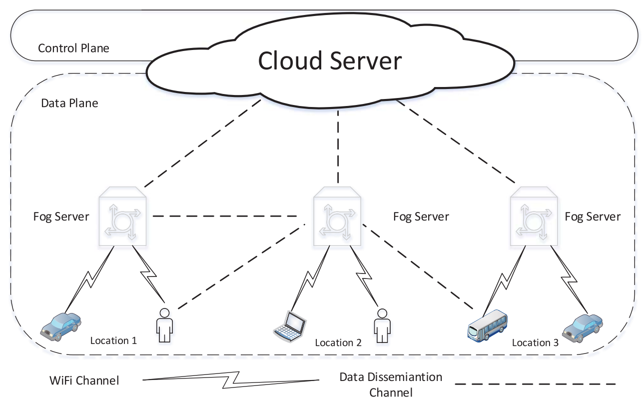

Fig. 2. Hybrid data dissemination model in Fog computing.

is also available. Assuming that an on-board Fog server is installed on a tourism bus, so that passengers on this bus can access its Fog server to watch movies or play games. If a passenger wants to find new contents, such as "just in" news, Fog server can use the cellular network to retrieve this content immediately. When this bus travel to a small town along its route, it can synchronize its content with the Fog server located in this small town to update both servers' content list. If the Fog server in this small town has some content while other small towns along the route do not have, this tourism bus could download these contents into its local storage and carry to those small towns where they need these contents.

With the above DTN-based data dissemination techniques, we propose a hybrid data dissemination model, as shown in Fig. 2. This hybrid model not only includes the normal data dissemination between Cloud servers and Fog servers, but also involves large amount low-cost DTN-based data disseminations, which can be used between Fog servers and mobile users and among Fog servers. To organize these data dissemination, we reidentify the function of Cloud servers. In this model, the main function of Cloud server is to act as the "control plane" to determine the Fog server needed to be updated with the required content and control data dissemination process, as shown in Fig. 3. Fog servers and part of Cloud servers are treated as "data plane" to provide data dissemination service.

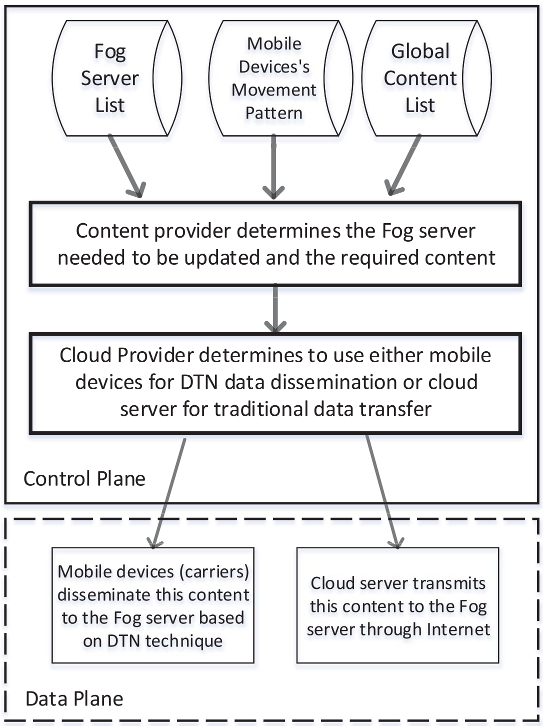

Fig. 3. Control plane and data plane in this model.

This data dissemination model has three components, namely as *data structures*, *protocol messages*, and *algorithms*. Data structures use tables to store key information which is used to determine the path of data dissemination. Protocol messages use various tapes of messages to discover content and mobile devices associated with a Fog server, exchange content list, and other tasks to learn and maintain accurate information about the network. Algorithms are used to calculate the best data dissemination path.

Cloud server in this model needs to have an overall information and its data structures include the following tables.

1) *Fog Server List Table:* A table to record all Fog servers, which are managed by Cloud server. This table includes Fog server's ID, content ID in each of Fog servers, mobile device ID associated with each of Fog servers.
2) *Global Content List Table:* A table to record all public contents (not include these private content created by Fog server owner) in Fog servers or supposed to be in Fog servers. This table includes content ID, the size of each contents, Fog server's ID (for these Fog servers who have this content), date of update, and validation time.
3) *Mobile Devices's Movement Pattern Table:* A table to record mobile device's ID, Fog server ID (whom mobile device linked before), linked time, social attribute, and geographic movement pattern.

A Fog server needs to have a table to record content ID, the size of this content, mobile device's ID which linked with this Fog server, the linked duration of this mobile device. For mobile devices, they need to record the content ID which they carry on, their movement path, time duration with a Fog server and its ID.

In order to collect and exchange the above information, several data messages are used in this model.

1) *Hello Message Between Fog Servers and Cloud Server:* An update message from a Fog server to its Cloud provider, which includes its content ID and associated mobile devices ID. This is a triggered message.
2) *DTN Data Dissemination Request Message:* A message sent from Cloud provider to a Fog server. When Cloud provider determines there is content need to be updated for Fog server A, if Fog server B has this content and its associated mobile device has potential move to Fog server A, a DTN data dissemination request message is sent to Fog server B to ask it to disseminate the content through that mobile device.
3) *DTN Data Dissemination Accept Message:* A message sent from Fog server to its Cloud provider. Once a Fog server received a DTN data dissemination request message and it sends the content to the corresponding mobile device, it sends this DTN data dissemination accept message to its Cloud provider to confirm that this content has been sent out.
4) *DTN Data Dissemination Decline Message:* A message sent from Fog server to its Cloud provider. Once a Fog server received a DTN data dissemination request message, but its associated carrier (mobile device), for some reason, does not receive the complete content before this carrier leave the current Fog server. In this case, the DTN data dissemination decline message is sent back to the Cloud provider.
5) *DTN Data Dissemination Acknowledgment Message:* A message sent from Fog server to its Cloud provider. When a Fog server receives the assigned content from carrier, it sends this acknowledgment message to Cloud provider to confirm that this DTN data dissemination is completed.

Algorithms together with other operations in this hybrid data dissemination model are described in the following section.

B. Hybrid Data Dissemination

Hybrid data dissemination is determined by control plane, as shown in Fig. 3, where Cloud provider in the control plane has the global information to control the data plane. The main data flow control algorithm conducted by Cloud provider is illustrated in Algorithm 1, where Cloud provider checks its global Fog server and content lists to determine the Fog server that needed to be updated, and the required content. It also checks which Fog server has this content. If none of Fog server has this content, Cloud provider sends updated content to that Fog server directly by using traditional Cloud-based techniques, such as broadband and cellular networks. Otherwise, the DTN-based data dissemination is applied by using Algorithm 2 to choose mobile devices, which are connecting with these selected Fog servers, as carriers to provider DTN-based data dissemination services.

The carriers selection is based on their delivery time and delivery probability (Algorithm 3). A predetermined content delay threshold, T_{delay}, which is an attribute of this content and

Algorithm 1 Data Flow Control Algorithm

Step 1: Cloud provider compares its "Global Content List" table with "Fog Server List" table to determine which Fog server is needed to be updated. In this case, Fog sever F_d is determined and content C needs to be updated.
if There is no other Fog server having this content **then**
  Cloud provider sends this content to the Fog server directly, which is the same as traditional Cloud service and this dissemination process is finished.
else
  Move to the next step
end if
Step 2: Cloud provider determines a list of Fog servers, $< F_{c1}, F_{c2}, F_{c3}, \ldots >$, which have this content.
Step 3: Algorithm 2 is used to select n most suitable carriers, $Carrier_n$, to provide this DTN dissemination service.
if n greater than 0 **then**
  Move to the next step
else
  Cloud provider sends this content to the Fog server directly, which is the same as traditional Cloud service and this dissemination process is finished.
end if
Step 4: Cloud provider sends "DTN Data Dissemination Request" message to each of selected Fog servers to ask them send the content C to F_d by using the carrier (mobile device) determined in **Step 3**.
Step 5: Once a Fog server receives "DTN Data Dissemination Request" message, it sends the content C along with the destination, F_d, to the selected carrier.
if Content C is transferred to the selected carrier completely **then**
  This Fog server sends the "DTN Data Dissemination Accept" message to its Cloud provider and move to the next step.
else
  This Fog server send the "DTN Data Dissemination Decline" message to its Cloud provider. When Cloud provider receives this message, it repeats *Step 3* to get the "n+1" Fog server, if it has, and continue from *Step 4*.
end if
Step 6: Once F_d receives the content C, it sends "DTN Data Dissemination Acknowledgement" message to Cloud provider.
Step 7:
if Cloud provider receives the "DTN Data Dissemination Acknowledgement" message within a pre-defined period, T_{delay}, in Algorithm 2 **then**
  It updates "Fog Server List" and "Global Content List" tables, and this data dissemination is finished
else
  It repeats from the *Step 1*
end if

不应该是重复执行 而应该是条件放得更宽 寄希望于多个device得共同努力

can also be treated as content delivery priority, is provided by the Cloud provider. Only those mobile devices (carriers) with a shorter delivery time compared with the predetermined delay time, and a higher delivery probability are selected as potential DTN-based data dissemination carriers.

Once these carriers are chosen, Cloud providers send DTN data dissemination request message to each of the selected Fog servers to ask them to send the required content to the Fog server which is needed to be updated. If the content is transmitted to the carrier successfully, a DTN data dissemination accept message is sent back to Cloud provider confirming this content has been sent out. Otherwise, a DTN data dissemination decline message is sent. For example, a mobile device (carrier) left a Fog server's coverage area.

When the Fog server, who needs this content, receives the content, it sends a DTN data dissemination acknowledgment message to Cloud provider to confirm it has received the content and this DTN-based data dissemination process is finished. Otherwise, Cloud provider needs to reselect mobile nodes as carriers or directly sends the content using traditional method. Detailed hybrid data dissemination processed are illustrated in Algorithms 1–3, and notations used in these three algorithm are explained in Table I.

C. Privacy and Reliability of FogRoute

The proposed hybrid data dissemination model in Fog computing is promising for resource utilization and network performance improvement. However, it still has several concerns, particularly from privacy and reliability point of views.

1) How to Maintain the Privacy of the Content: Privacy is a main security concern [17], [18] in the DTN-based data dissemination. Selected mobile devices need to store, carry, and forward a content from the current Fog server to the destined Fog server, where the content temporal stored in its storage does not belong to it. In that case, if a mobile device steals a glance of this content, it will cause potential security leakage. For example, a new product is coming to market in two days and its video demo and price information is being distributed among selected fog severs. If one of mobile devices detects this content and sells this information

Algorithm 2 DTN Data Dissemination Carrier Selection Algorithm

Step 1: Cloud provider determines the affordable delay time, T_{delay}, of this content. T_{delay} Cloud be treated as the priority of this content.

Step 2: Cloud provider checks its "Fog Server List" and "Mobile Devices's Movement Pattern" tables to find the list of mobile users accessed F_d before, $MobList_d(i)$, and their average connection time with F_d, $Time_d(i)$, where i is the ID of connected mobile device.

Step 3: These mobile devices with a short connection time are filtered out, as they are not able to upload the content to the Fog server:

for each of mobile device in $MobList_d(i)$ **do**

if

$$\frac{Size_C}{Speed_i} > Time_d(i)$$

then

This mobile device is filtered out from $MobList_d(i)$ and a new list $MobList'_d(r)$ is formed, where r is the number of mobile device meeting the above condition

end if

end for

Step 4: $MobList'_d(r)$ is further classified into two categories, *scheduled* and *non-scheduled* visit lists. Scheduled visit list stores these mobile devices which are predetermined to visit a particular Fog server, such as airport shuttle bus. The rest of filtered mobile devices are classified into the non-scheduled visit list.

Step 5: For scheduled mobile devices, Si, as long as its delivery time, which is the time from now to its next scheduled visit time, is within the T_{delay}, it is added into the DTN data dissemination carrier list, $< Carrier_{S1}, Carrier_{S2}, \ldots, Carrier_{Sx} >$, where x the total number of carriers selected to add into the carrier list.

Step 6: Non-scheduled mobile device list, NSi, is re-ordered by mobile devices' delivery probability to F_d based on Algorithm 3. Cloud provider select the top y mobile devices according their delivery probabilities to add them into the DTN dissemination carrier list, where the number of y is the largest number to satisfy the following condition:

$$\frac{\sum_{i=1}^{x} DeliTime_{Si} + \sum_{i=1}^{y} DeliTime_{NSi}}{x+y} < T_{delay}$$

既然是都发送 那么最早到达的pkt才会作为delay.

End: Now $x+y$ mobile devices are selected as carriers to provide DTN data dissemination service.

to this product's competitor, it will potentially involve a huge lost of this product.

To overcome this problem, asymmetric cryptography [19] is deployed in the proposed model. Every Fog server has public and private keys, where it stores the private key by itself and upload its public key into Cloud provider, which is the trustable control plane. When Cloud provider determines carriers, it passes the destined Fog server's public key to mobile device's associated Fog server, where this Fog server uses the public key to encrypt the content. Without the paired private key, carriers cannot disclose the stored content and content's privacy is protected.

2) How to Make Sure Mobile Devices Are Willing to Carry Contents: A key factor affecting the reliability of DTN-based data dissemination is whether mobile nodes are willing to store, carry, and forward the assigned content or not. Mobile devices, particular for those nonpower supply devices, have a relative small amount of storage space and limited power. Why they want and how to motive them to participate into the DTN-based data dissemination become an important research issue.

Some incentive DTN forwarding schemes [20] and [21] had already been proposed, however, the data forwarding among carriers when they are traveling to the designated Fog server, is not the main concern in this paper. Instead, we only consider the "one hop" DTN delivery, where a mobile device downloads the required content, stores it into its local storage, carries to the destined Fog server and forwards this content to it. A light incentive scheme is deployed in this model, which likes a "loyal membership." Mobile devices who are willing to deliver content and have a high delivery success ratio will be rewarded a high membership points. Membership points can be used to subscribe those pay-video services or redeem a higher discount voucher from Fog servers or Cloud provider.

IV. Simulation

Simulation of the proposed hybrid data dissemination is presented in this section to show the performance of FogRoute. As data dissemination through Cloud infrastructure is a very mature field, the main focus in our simulation is the performance of DTN-based off loading. The first section illustrates the data set we are going to use and the simulation setup. The second section analyzes the simulation results.

A. Simulation Setup

To simulate the DTN-based data dissemination and particular for their mobile carriers' selection, we use the real taxi trace file and the public transport data, such as bus, from the city center of Rome, Italy generated by Amici *et al.* [22]. The data

Algorithm 3 Mobile Device Delivery Probability

Step 1: For each of mobile devices, m, Cloud provider collects its contact frequency with F_d, $ConFre_m$, geographic locations and visit times of the three most recently visited Fog servers, $Loc_m < Lan, Lon, T >$.

Step 2: Based on the three most recent visited history, $Loc_m < Lan, Lon, T >$, and real distance from the map, average movement speed and direction of mobile device m could be generated as $Speed_m$ and $Direction_m$.

Step 3: The expected delivery time from mobile device m to Fog server F_d, $DeliTime_m$, is calculated by using $Speed_m$, $Direction_m$ and the geographic distance between both them.

if $DeliTime_m > T_{delay}$ **then**

The delivery probability of this mobile device, $DeliProb_m$, is marked as 0 and this algorithm is finished

else

Move to next step

end if

Step 4: Assume there are n suitable mobile devices left in this step. The overall delivery probability of mobile device m is calculated as:

$$DeliProb_m = \frac{ConFre_m}{\sum_{i=1}^{n} ConFre_i} \times (1 - \frac{DeliTime_m}{\sum_{i=1}^{n} DeliTime_i})$$

and each of them is added into the delivery probability list, $DeliProbList[n]$.

Step 5: Sort $DeliProbList[i]$ in ascending order

Set $u = 1, j = n$

while $u \le n$ **do**

  while $j > u$ **do**

    if $DeliProbList[j-1] > DeliProbList[j]$ **then**

      swap($DeliProbList[j-1]$, $DeliProbList[j]$)

    end if

    $j--$

  end while

  $u++$

end while

This delivery probability list is ready to be used for Algorithm 2.

set collects 370 taxi cabs' movement trace in the city of Rome for a period of 6 months. Each of taxis is equipped with an Android OS tablet running an app to update its current position to a server in every 7 s with its latitude and longitude, and this trace file only records those traces occurred in the center of Rome within a 8 km×8 km area with the coordinates pairs as (41.856, 12.442) and (41.928, 12.5387). As the city of Rome is characterized by very thin and congested roads, the average speed of taxis is slow and only 12.29 km/h.

For the simulation purpose, the one month most stable trace collected from February 1, 2014 to March 2, 2014 is used. Fig. 4 demonstrates the overall reported positions of these 370 taxis in one day period, which is indexed by its latitude and longitude in the 8 km×8 km area. As some locations are reported more than 6000 times, while there are still some locations are reported only 0 or 1 time, to make this figure more readable, we capped the daily reported frequency as 300 times. According to this figure, majority of place in this area have been visited by at least one taxi, as long as they are car reachable. If we further use the investigation in [22], where the realistic wireless coverage of the vehicle-mounted Android OS tablet is 50 m by using 2.4- and 5-GHz communications, the wireless coverage area of each taxi is becoming much larger.

In addition of these nonscheduled taxi traces, we retrieved the schedule of bus traces in the city of Rome from ATAC (Tramways Company and Coach of the Municipality of Rome) [23], which has all public transport data of Rome, such as bus route, travel frequency, and travel time between two bus stops. Bus routes coverage of the proposed simulated area is abstracted in Fig. 5. Wireless coverage of these scheduled bus services cover the most popular tourism area and cafe shops in the city area, where Fog server could be deployed. Fifty Fog servers are deployed in the simulation areas to provide data dissemination services.

参数 通信范围设定 值得关注

To conduct this simulation, we implement a Java-based discrete event driven simulator. This simulator simulated taxis and buses' movements with their times and locations. Fifty Fog servers are deployed in the simulation area with random latitudes and longitudes. Contents used in this simulator were randomly generated and their sizes are in the range of 1 MBs to 6 GBs, and they are distributed among in different Fog servers. All mobile devices' movements, content distribution, Fog server associated devices, etc., are stored in central to simulate the Cloud environment.

Two main experiments are conducted to test the performance of the proposed model. The first simulation is to test the affect of expected delay to the final delivery success ratio. The ~~second~~ experiment is to test the convergence time of data dissemination for each of Fog servers. All experiments are simulated ten times and their average results are recorded.

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TABLE I
NOTATIONS

Notation	Definition
F_d	A Fog server needed to be updated (the destination of data dissemination)
C	A content needed to be updated and disseminated
F_i	The Fog server i
$Carrier_i$	A content carrier (mobile device) i to provide DTN based data dissemination service
T_{delay}	The maximum affordable delay time of a content. It is a time period from now to its must updated time, such as a shopping center promotion video must be released on every Wednesday
$MobList_d(i)$	The ith mobile device (carrier) in the mobile list attached with Fog server d
$Time_d(i)$	An average connection period between mobile device i and Fog server(d). It is a maximum time window used to upload/download a content to a Fog server
$Size_C$	The size of content C
$Speed_i$	The wireless transmission speed of mobile device i
Loc_i $< Lan, Lon, T >$	The geographic location vector of mobile device i visited at latitude Lan and longitude Lon on time T
$Direction_i$	The expected movement direction of mobile device i
$DeliTime_i$	An average content delivery time of Carrier i to the destined Fog server
$ConFre_m$	A contact frequency between the mobile device m and its destined Fog server
$DeliProbList[n]$	A list to store all carriers (mobile devices) delivery probability to the destined Fog server

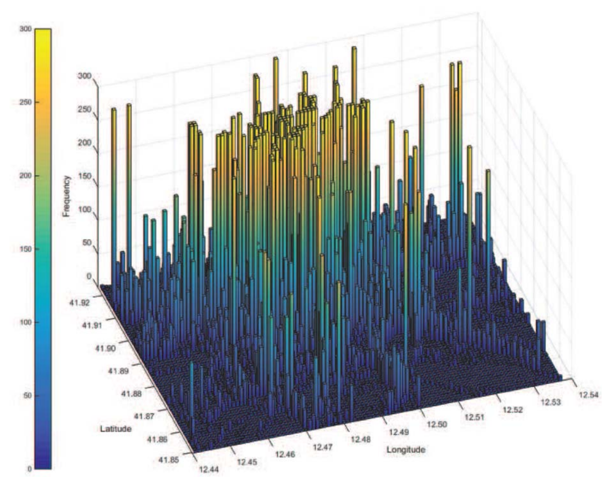

Fig. 4. Frequency of taxi reported locations in the center of Rome.

B. Simulation Result

Delivery success ratio is the main concern and key indicator when designing and selecting a data dissemination model. It is particularly important for this hybrid model in Fog computing, as the main target in this model is to disseminate content into the selected Fog server within the expected delay time. In that case, the content provider or Cloud administer needs to find a suitable expected delay from both economic and reliability point of views.

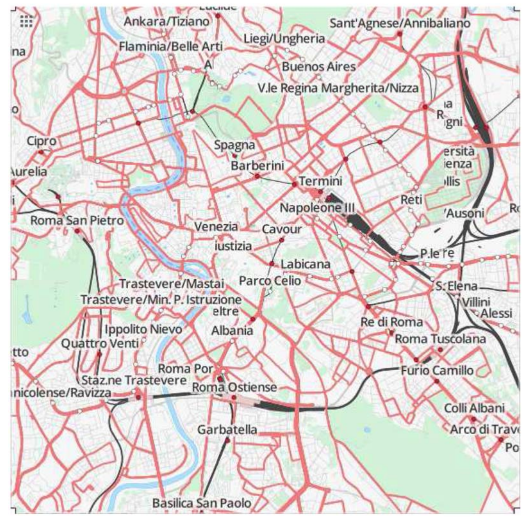

Fig. 5. Abstracted bus routes in Rome with bounds' coordinates pairs as (41.856, 12.442) and (41.928, 12.5387).

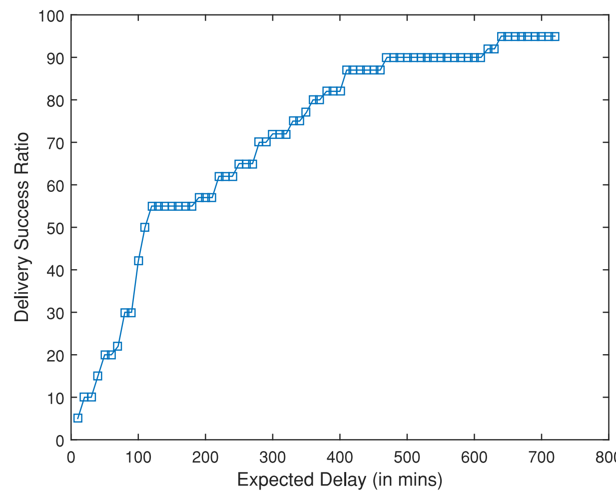

Fig. 6. Performance of delivery success ratio with different expected delay.

Fig. 6 shows the average delivery success ratios with different expected delays. In this experiment, the content to be disseminated and the Fog server whose content needed to be updated are randomly chosen. This result demonstrates that the expected delay has a great impact to the delivery success ratio. When the expected delay is less than 2 h, the average deliver success ratio is less than 50%. When the expected delay time is increased to 6 h, the average deliver success ratio reaches to 80%. When the expected delay time is larger than 8 h, the delivery success ratio is more than 90%. After 10 h, the delivery success ratio is converged at 95%.

The above results give a clear picture of how to use the proposed hybrid data dissemination model. For example, when the content dissemination is not that urgent, say a half of day delay is affordable, the DTN-based data dissemination is the best choice from both economic and reliability point of view. If the content needed to be disseminated to other Fog servers in 1 or 2 h, such as important news, DTN-based data dissemination

在paper的设定里面(内容分发网络)，node没有内存限制。
delay限制 和 投递率

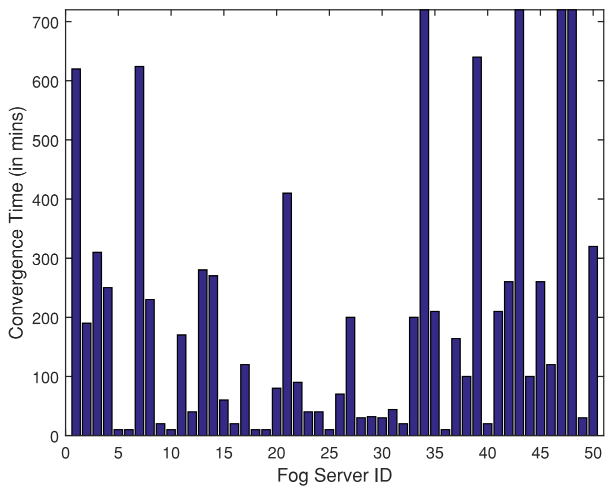

Fig. 7. Performance of convergence time for each Fog server.

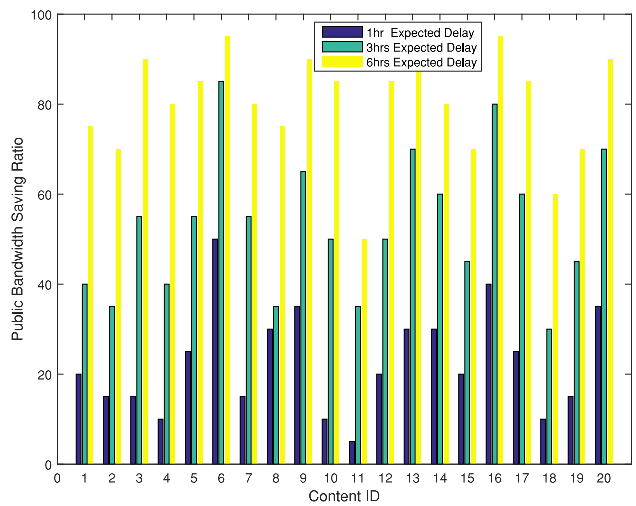

Fig. 8. Performance of public bandwidth saving.

could be used, but a Cloud-based data transmission channel should be ready as a backup.

Convergence time is another key factor to reflect how efficient of a data dissemination model, which measures the time spent on a Fog server to receive all contents. In this experiment, we randomly select 20 contents from the list and set up their destinations to each of Fog servers. We record the time for each of Fog servers to receive a content and the convergence time is the total time of a Fog server to receive these 20 contents. To make this content dissemination more general, size of contents are vary from 1 MBs to 6 GBs and there are 50 Fog servers all together.

Fig. 7 shows the average convergence time for each Fog server, where seven Fog servers could complete the data dissemination in just 10 min! In summary, there are 15 Fog servers could reach the convergence in 1 h and 27 Fog servers reach the convergence in 2 h, which means the data dissemination to more than half of total Fog servers with 20 contents could be completed within the first 2 h. In addition, there are 46 Fog servers all together could reach the convergence within 11 h, while four Fog servers cannot be converged within 12 h.

The above results demonstrate the proposed model is very suitable for a large number of content dissemination based on DTN technique. It can be seen that 92% of overall contents could be successfully disseminated to each of Fog servers within a day, and there are only 4% of Fog servers cannot successfully update their content list, where a higher cost Cloud-based data dissemination is therefore required to be deployed.

Compared with the traditional model, another advantage of the proposed model is on the public bandwidth saving. With the advances in modern Cloud network technique, the cost per unit bandwidth has dramatically decreased, which, however, is accompanied by the surge increase data volume to be transmitted, such as high resolution videos. For example, for a 1TB bandwidth on Microsoft Azure Cloud service, it takes around $100. In this experiment, the ratios of public bandwidth saving with different expected delay are demonstrated.

Fig. 8 demonstrates the performance of public bandwidth saving for three different metrics, namely 1, 3, and 6 h expected delays, where the expected delay is used to identify the affordable delay for a certain content. Twenty contents are randomly selected and their bandwidth saving ratios are displayed in bars. It can be seen that when the expected delay is 1 h, the average bandwidth saving ratio is 30%, and with the expected delay increased to 3 h, the average bandwidth saving ratio is 55%. Once the expected delay is increased to 6 h, the average bandwidth saving ratio reaches to 85%.

The simulation results demonstrate that the proposed model can dramatically decrease the public bandwidth usage, while maintain a high data dissemination standard. It shows that 85% of public bandwidth can be saved in the simulated scenario, when the delay of data dissemination is up to 6 h. For those high volume and delay-tolerable contents, such as video and movie, 6 h is a reasonable and affordable delay time.

Is summary, these experiment results show the proposed hybrid data dissemination model not only saves public bandwidth and utilizes network resource, but also has a higher delivery success ratio with a lower end to end delay. It proves the FogRoute is a workable, efficient and reliable model in Fog computing paradigm.

V. Conclusion

In this paper, we have proposed a hybrid data dissemination model in Fog computing by utilizing both DTN and Cloud techniques. These contents with higher volume and lower timeliness, such as high definition video, could be disseminated by delay-tolerant technique. While these contents with lower volume and higher timeliness, such as emergency news, could be disseminated with current Cloud technique. The proposed model is central controlled by content provider or Cloud administer and all Fog servers are distributed deployed in local areas. DTN-based data dissemination is based on human (mobile devices) and vehicles. Experiment results demonstrated the proposed model has a higher delivery success ratio and lower end to end delay, which proved it is not only workable, but also reliable and efficient in term of data dissemination in Fog computing.

For the future work, we intend to extend the current proposal to a more generalized scenario as follows. The currently carrier forwarding algorithm in DTN is based on one hop delivery only, where carriers download content from content provider (source Fog server), carry to the destination Fog server and upload the content to it. In that case, if a mobile device has limited connect with the destination Fog server, it cannot be selected as carrier. In the future work, the forwarding algorithm could be designed as relay-exchange-forwarding, where mobile devices could exchange/multicast contents among themselves when they are moving to the final destination.

作者值得关注

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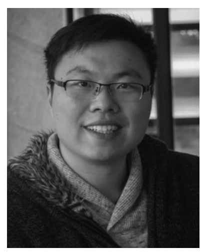

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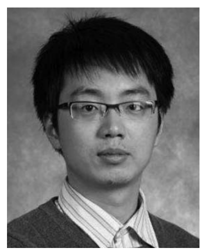

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